BRL-TR-3285

AD-A242 626

TECHNICAL REPORT BRL-TR-3285

BRL

AN ALTERNATIVE HARDWIRE TELEMETRY TECHNIQUE

TODD E. ROSENBERGER
NATHAN E. BOYER
JOSEPH W. COLBURN
PHILLIP G. REEVES

OCTOBER 1991

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

NOTICES

UNCLASSIFIED

REPORT DOCUMENT PAGE			Form Approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project(0704-0188), Washington, DC 20603.			
1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE October 1991	3. REPORT TYPE AND DATES COVERED Final, Mar 90 - Nov 90	
4. TITLE AND SUBTITLE An Alternative Hardwire Telemetry Technique			5. FUNDING NUMBERS PR: 1L161102AH43
6. AUTHOR(S) Todd E. Rosenberger, Nathan E. Boyer, Joseph W. Colburn and Phillip G. Reeves			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES) USA Ballistic Research Laboratory ATTN: SLCBR-DD-T Aberdeen Proving Ground, MD 21005-5066			10. SPONSORING/MONITORING AGENCY REPORT NUMBER BRL-TR-3285
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for Public Release - Distribution is Unlimited			12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The effect of high frequency pressure oscillations on projectile integrity and projectile payloads is a key technical issue in the liquid propellant gun program. A great deal of effort has been directed toward the study of varying the gun system and propellant to alleviate, or at least dampen, pressure oscillations. A project was initiated to study the effects of oscillations on the projectile in a 30-mm Concept VI Regenerative Liquid Propellant Gun. A unique hardwire telemetry technique was used to record projectile base pressure and acceleration through the regime in which pressure oscillations occur. A hollow, fiber composite extension rod mounted to the front of the instrumented projectile supports the transducer leads and shields them from the inbore environment. Conventional hardwire telemetry problems such as the projectile impacting with the wire before measureable travel has occurred and the projectile cutting the wire between itself and the bore are eliminated. This report describes the instrumentation and test setup of this unique hardwire telemetry technique. Data recorded using this method are presented for both liquid and solid propelling charges. Effects of high frequency pressure oscillations on the projectile are examined and future telemetry design ideas are discussed.

14. SUBJECT TERMS			15. NUMBER OF PAGES
Telemetry, Instrumented Projectile, Liquid Propellant Guns, Pressure Oscillations Oscillation, Liquid Gun Propellants			25
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

INTENTIONALLY LEFT BLANK.

TABLE OF CONTENTS

INTENTIONALLY LEFT BLANK.

LIST OF FIGURES

Figure | Page

INTENTIONALLY LEFT BLANK.

1. INTRODUCTION

High frequency pressure oscillations have been observed in regenerative liquid propellant gun data. These pressure oscillations have been observed in calibers ranging from 25 mm through 155 mm (Mandzy, Cushman, and Magoon 1987; Pate and Magoon 1985; Mandzy et al. 1983; Magoon, Haberl, and Purtee 1989; Watson 1989; Knapton and Watson, to be published). The effect of pressure oscillations on projectile integrity and projectile payloads is a key technical issue in the liquid propellant gun program. A great deal of effort has been directed toward the study of varying the gun system and propellant to alleviate, or at least dampen, these pressure oscillations. Interest has been expressed in initiating programs to determine the effects, if any, that oscillations have on the projectile. A project was initiated to study the effects of chamber pressure oscillations on the projectile in a 30-mm Concept VI RLPG.

In order to determine the effects of pressure oscillations, the projectile must be instrumented with transducers that will allow projectile acceleration and base pressure data to be recorded. Various methods of transferring this information to a medium where it can be recorded have been devised for both small and large caliber solid propellant gun systems (Evans 1985; Craig 1973; Morrow 1972). Most of these methods required onboard data recorders, wire collection scoops, complex transmitting and receiving electronics, or other elaborate and expensive data transmission schemes. Due to budget and gun system constraints, none of the methods of telemetry that were found in the literature were suitable for our application. The scoop methods were limited to lower velocities than we were expecting (800-1000 m/s), and it was uneconomical to machine a scoop for each test due to the lack of a proper soft recovery system. Space and bandwidth constraints made any type of radio frequency telemetry or onboard recording system too large and too expensive. Thus, a low cost hardwire telemetry method was designed that took advantage of high strength composite fiber technology to maintain contact between the transducers and the recording system during the interior ballistic cycle. To our knowledge, this method had never been used successfully in the interior ballistic environment. This paper describes the early development of a hardwire telemetry method that is being investigated at the BRL. Preliminary data are presented, a partial analysis is put forward, and improvements to this technique are suggested.

2. METHODOLOGY

The hardwire telemetry method is an inexpensive method of transferring data from an instrumented projectile to a data recording medium. A hollow composite extension rod is mounted on the front of an instrumented projectile through which the transducer wires are threaded. A composite rod provides significant strength to support the wires at greatly reduced mass as compared to an equal strength metal configuration. As the forces generated are primarily due to acceleration loading of the projectile, minimization of the support system mass is of utmost importance. The extension rod protects the wires from the inbore environment and alleviates any pinching of the transmission wires between the projectile and the bore during the first several feet of travel. These wires are then extended out of the muzzle and attached to a stationary blast stand to keep them from resting on the inside of the gun tube wall. Data from an onboard accelerometer and base pressure gage are transmitted over the wires, through signal conditioning hardware external to the gun system, and recorded until the wires are destroyed.

3. EXPERIMENTAL

3.1 Instrumentation. Testing of the new hardwire telemetry technique was performed in a 30-mm Concept VI RLPG. Figure 1 shows the Concept VI RLPG (Knapton, Watson, and Boyer, to be published). The top half of the drawing shows the system before firing and the bottom half shows the system after firing. Chamber pressure measurements were taken in the J, C, and A planes as shown in the figure. Three pressure measurements were also taken in the barrel. The barrel locations were at 3.8, 50.8, and 122.6 centimeters from the chamber end of the barrel. They are referred to as Barrel 1, Barrel 2, and Barrel

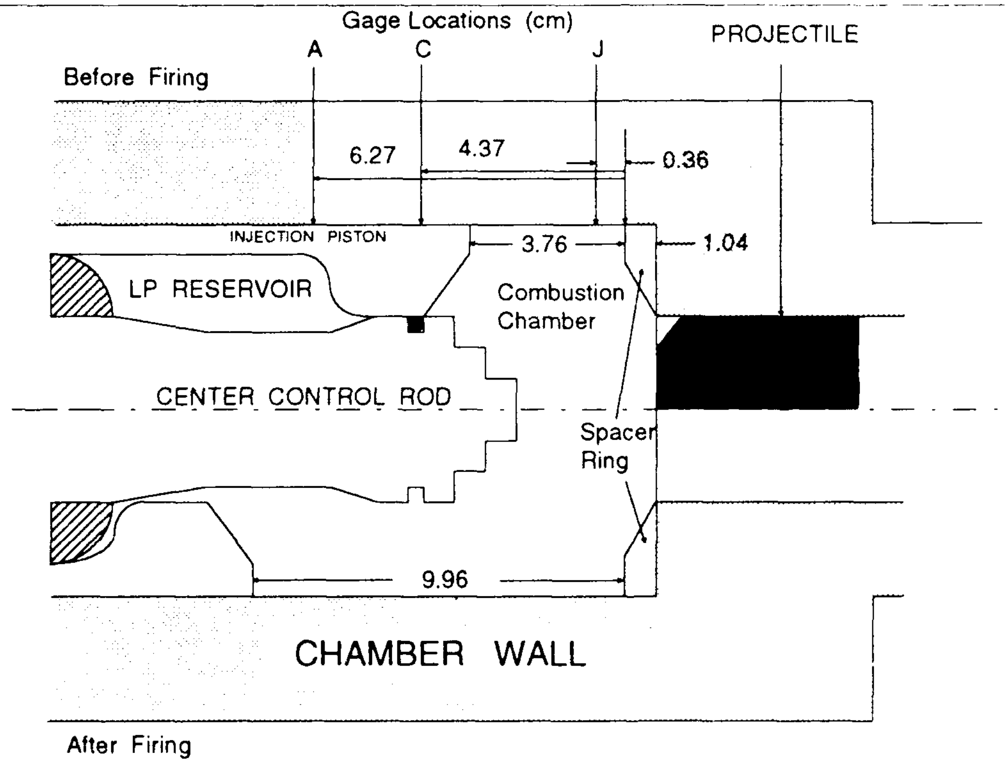

Figure 1. Concept VI Regenerative Liquid Propellant Gun

3, respectively. The barrel gages are used to measure tube pressure and discrete projectile position as determined by a sharp rise in pressure seen on the pressure versus time plot. All pressure measurements were made using Kistler 607C4 piezoelectric pressure transducers. A PCB 305M09 piezoelectric accelerometer was used to measure projectile acceleration. In addition to these measurements, microwave interferometry was used to measure projectile motion and an optical tracking device was used to measure the injection piston motion. Each test used 160 cm^3 of Liquid Gun Propellant 1845 and a 3.6 gram solid propellant igniter (IMR 4350).

3.2 Telemetry Configurations. Four test rounds were fired. Three were performed using the hardwire telemetry technique described above. A fourth round, which was used as a baseline, had the transmission wires extended out the muzzle without the use of an extension rod.

The first test (415-56) configuration is shown in Figure 2. For this test a 30-mm brass projectile was machined to house an accelerometer. A hollow fiber composite extension rod 107 centimeters in length was mounted to the front of the projectile. Nylon reinforced wires [32 gauge] were connected to the accelerometer and threaded through the inside of

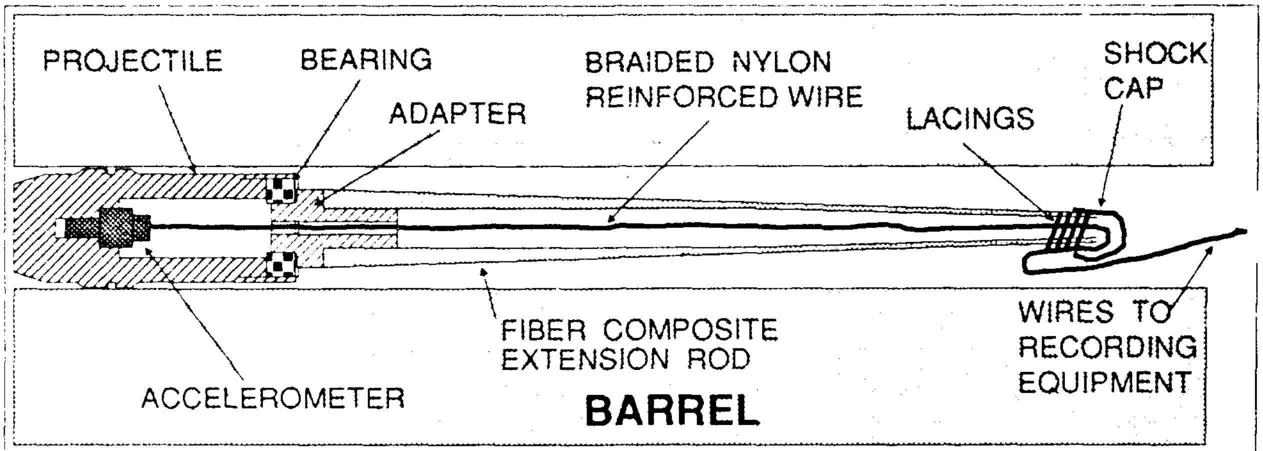

Figure 2. Telemetry Configuration Using Brass Projectile

the fiber composite extension rod. The wires were attached to the end of the rod in an attempt to keep them taut during early projectile travel. The purpose of the bearing was to minimize the angular acceleration of the extension rod as the projectile spun due to the rifling in the barrel. The mass of the projectile, rod, and wire was 276 grams. After test 415-56, it was determined that the material properties of the 30-mm brass projectile, when machined for an accelerometer, were too weak to withstand the ballistic loads that it was subjected to during firing. This determination led to the design of a steel projectile that could house both an accelerometer and a base pressure gage.

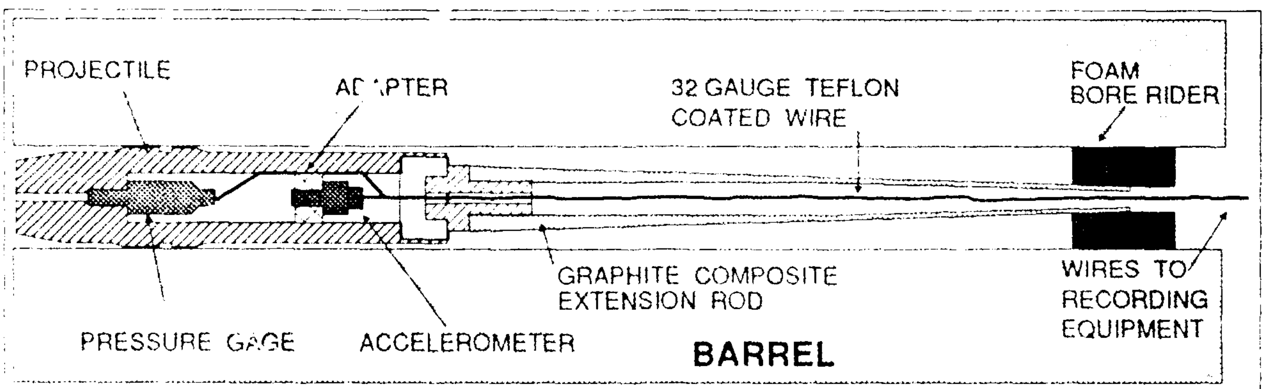

Figure 3. Telemetry Configuration Using Steel Projectile

Figure 3 shows the design of the steel projectile that was used in tests 415-68. 415-74, and 415-75. It consisted of a 10.2 cm steel projectile machined to house a base pressure gage and an accelerometer. Also included in the design is a brass rifling engraving slip band designed to reduce the rotational acceleration of the projectile and extension rod. This design used a lighter, stronger graphite extension rod measuring 68.6 cm in length. The same teflon coated wire [32 gauge] was used. A foam bore rider was included to alleviate any "whipping" of the end of the rod that may have occurred and to give the rod support. This projectile was retrieved and reused after firing. All that was needed was a new engraving band. The accelerometer was also able to be reused in tests 415-74 and 415-75. However, the base pressure gage was not reusable.

Since the projectile configuration of test 415-68 maintained its integrity, it was fired again (test 415-74) with two small changes. In place of the 32 gauge wire, 22 gauge wire was used. It was hoped that the larger wire would allow for greater projectile travel before data loss. The base pressure gage was also eliminated to simplify the test since base pressure data had been lost on the previous test. The mass of the projectile, rod, and wire was 720 grams. After firing, the projectile and accelerometer were both found to be reusable.

Test 415-75 was fired to obtain a data baseline for comparison with the tests using the extension rod. The same projectile and accelerometer used in the previous test were used without the aid of an extension rod. The mass of the projectile and 22 gauge wire was 600 grams. After firing, the projectile and accelerometer were both found to be reusable.

3.3 Results and Discussion. The results of the four round series are summarized in Table 1. Although projectile base pressure measurements were attempted, no discernible data was recorded.

Figure 4 shows a plot of measured projectile acceleration versus time and Figure 5 shows a plot of measured chamber pressure in the J-plane (gage J120) versus time for test 415-56. The pressure oscillations seen in Figure 5 are typical in the Concept VI RLPG.

Table 1. Summary of Telemetry Test Data

							DOMINANT FREQUENCY (kHz)		
TEST	PROJECTILE MASS (g)	WIRE GAUGE	MUZZLE VELOCITY (m/s)	BREAK VELOCITY (m/s)	BREAK DISTANCE (cm)	CHAMBER PRESSURE (MPA)	CHAMBER (J120)	PROJECTILE	BARREL (#1)
415-75	600	22	801	204	20.9	280	59	-	62
415-56	276	32	-	247	22.9	138	29	-	25
415-68	676	32	-	263	24.9	257	56	53	57
415-74	720	22	-	165	11.6	214	57	-	59

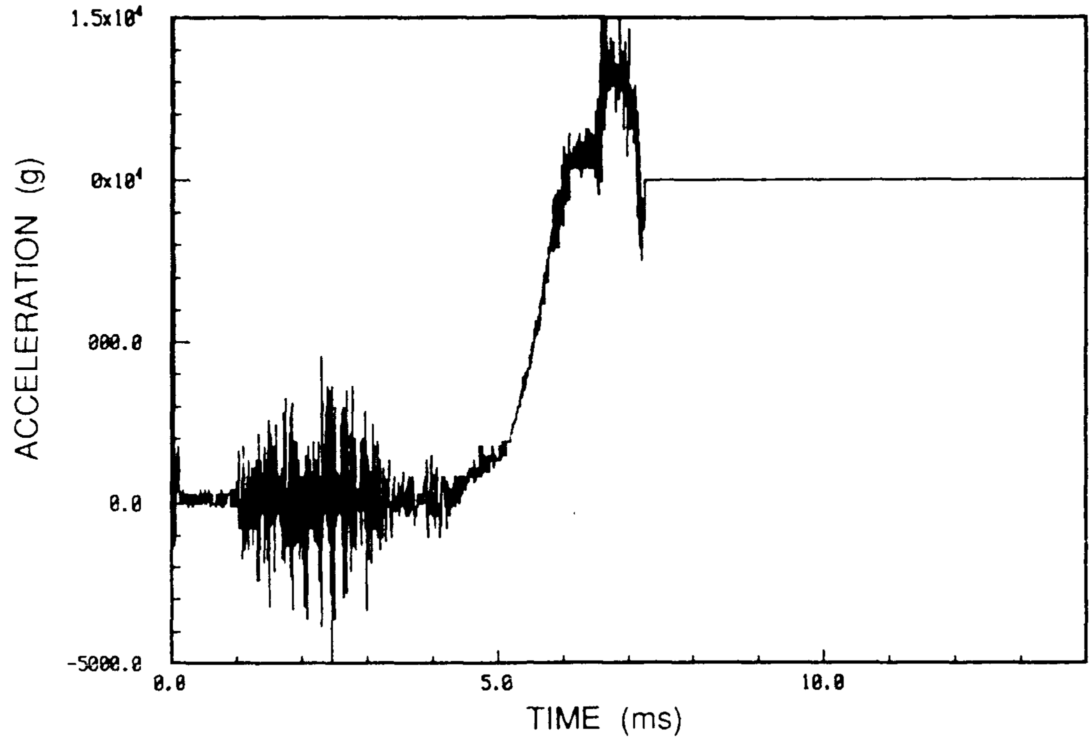

Figure 4. Test 415-56 Projectile Acceleration

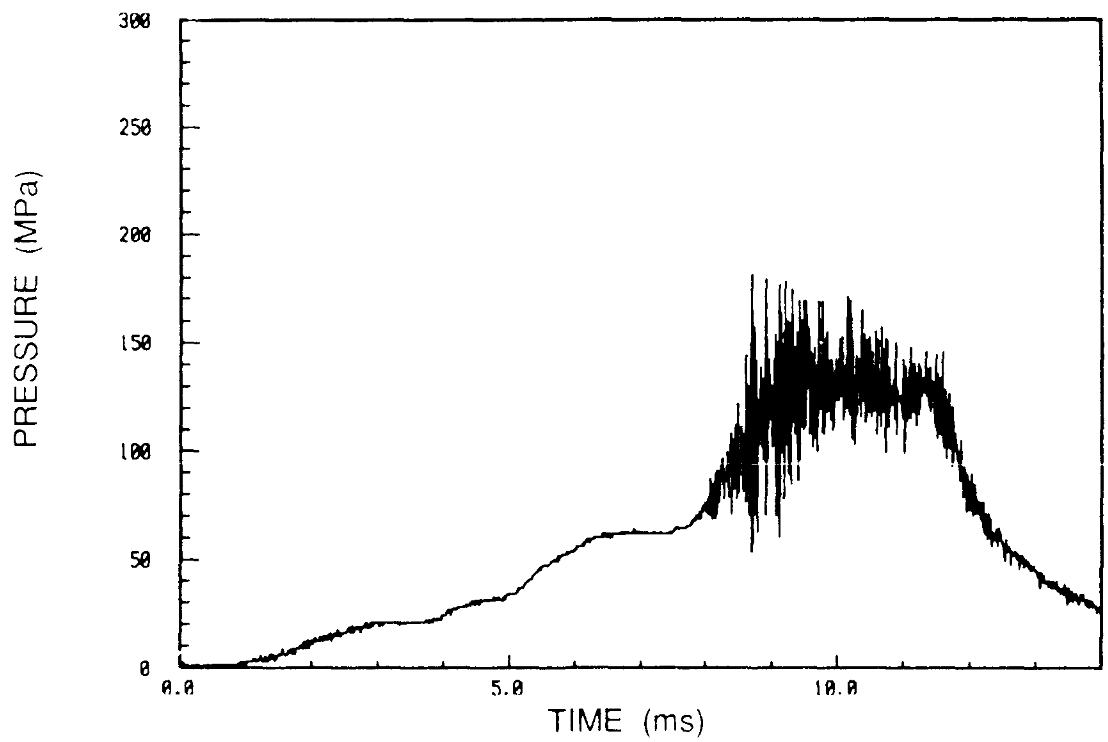

Figure 5. Test 415-56 Chamber Pressure (J120)

Comparing the accelerometer data to the pressure data, it is seen that the accelerometer transmission data were lost before the pressure oscillations began. The distance that the projectile traveled before transmission loss occurred was approximately 22.9 cm. This distance was determined by integrating the acceleration curve twice which produced a travel versus time curve for the projectile. By taking the time when the projectile passed the first barrel gage, and comparing this time with the corresponding time on the travel curve, an acceleration calibration adjustment was made. Using this information, the travel at time of transmission loss was calculated. Unfortunately all attempts to acquire interferometer data were unsuccessful, most likely due to the extension rod, and therefore further validation of these results was not possible. By using the same method, the velocity of the projectile at the time of transmission loss was determined to be approximately 247 m/s. A Fast Fourier Transform (FFT) of the chamber pressure and the first barrel pressure produced apparent dominant frequencies of 29 kHz and 25 kHz, respectively.

Figure 6 shows a plot of measured projectile acceleration versus time, Figure 7 shows a plot of measured chamber pressure versus time, and Figure 8 shows a plot of measured barrel pressure (barrel 1) versus time for test 415-68. Oscillations are apparent on the acceleration plot just prior to data transmission loss. Figures 9, 10, and 11 show expanded plots of projectile acceleration, chamber pressure, and barrel pressure, respectively. It is evident from Figure 9 that at least nine cycles of oscillations occur before data transmission is lost. The frequency of these oscillations was calculated by counting the cycles as shown in Figure 9 and was found to be 52.9 kHz. The frequency of the oscillations in the chamber was calculated over the same time and was determined to be 58 kHz. Likewise, the frequency of the oscillations on the barrel pressure was calculated over the same time and was determined to be 57 kHz. To confirm these frequencies, FFT's were done on each as shown in Figures 12, 13, and 14. The resultant dominant frequencies for the accelerometer, chamber pressure, and barrel pressure, were 53 kHz, 56 kHz, and 57 kHz, respectively. The authors were unable to draw any conclusions concerning the amplitude of the oscillations observed on the accelerometer data. The distance that the projectile traveled before data transmission loss was approximately 24.9 cm and the projectile velocity at that time was approximately 263 m/s.

Figure 15 shows a plot of measured projectile acceleration versus time and Figure 16 shows a plot of measured chamber pressure versus time for test 415-74. Comparing the accelerometer data to the pressure data, it is seen that the accelerometer transmission data was lost before the pressure oscillations began. The substitution of heavier gauge wire, which was expected to yield greater transmission distance, was detrimental to the telemetry system performance. The distance that the projectile traveled before transmission loss occurred was calculated to be approximately 11.6 cm. The velocity at the time of transmission loss was determined to be 165 m/s. An FFT of the chamber pressure and the first barrel pressure produced apparent dominant frequencies of 57 kHz and 59 kHz, respectively.

Figure 17 shows a plot of measured projectile acceleration versus time and Figure 18 shows a plot of measured chamber pressure versus time for test 415-75. Comparing the accelerometer data to the pressure data, it is seen that the accelerometer transmission data were lost before the pressure oscillations began. The distance that the projectile traveled before transmission loss occurred was calculated to be approximately 20.9 cm. The velocity at the time of transmission loss was determined to be 204 m/s. An FFT of the chamber pressure and the first barrel pressure produced apparent dominant frequencies of 59 kHz and 62 kHz, respectively.

Using the hardwire telemetry technique (test 415-68), an increase of 4 cm in data transmission distance was achieved over the round that did not use the extension rod technique (test 415-75). This increase in travel before loss of data transmission yields data that suggests there are oscillations being experienced by the projectile in the 30-mm Concept VI RLPG.

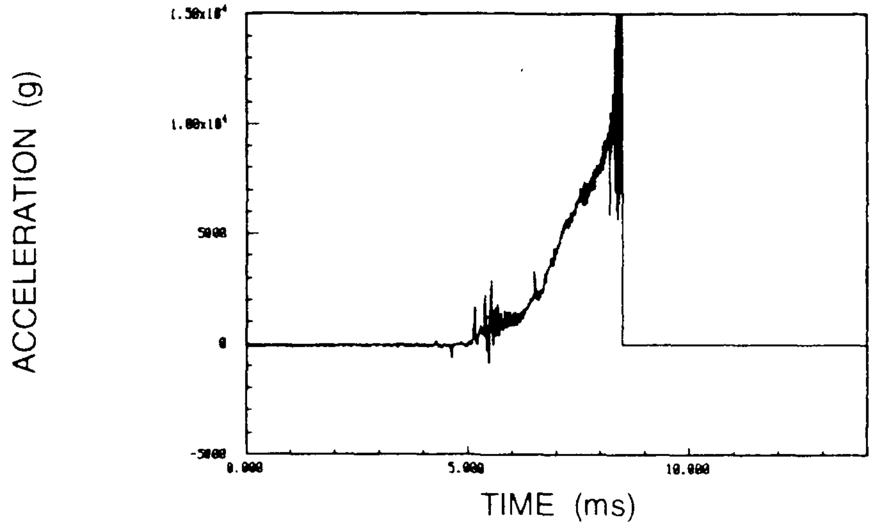

Figure 6. Test 415-68 Projectile Acceleration

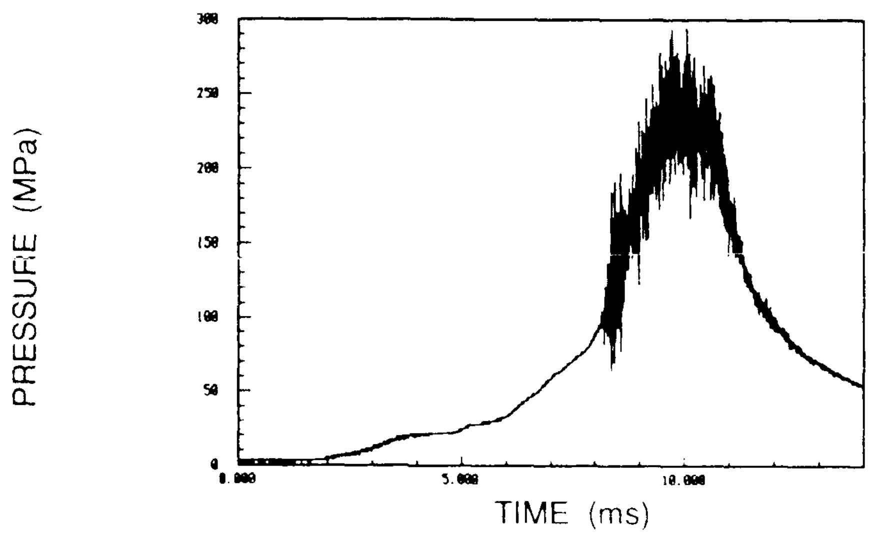

Figure 7. Test 415-68 Chamber Pressure (J120)

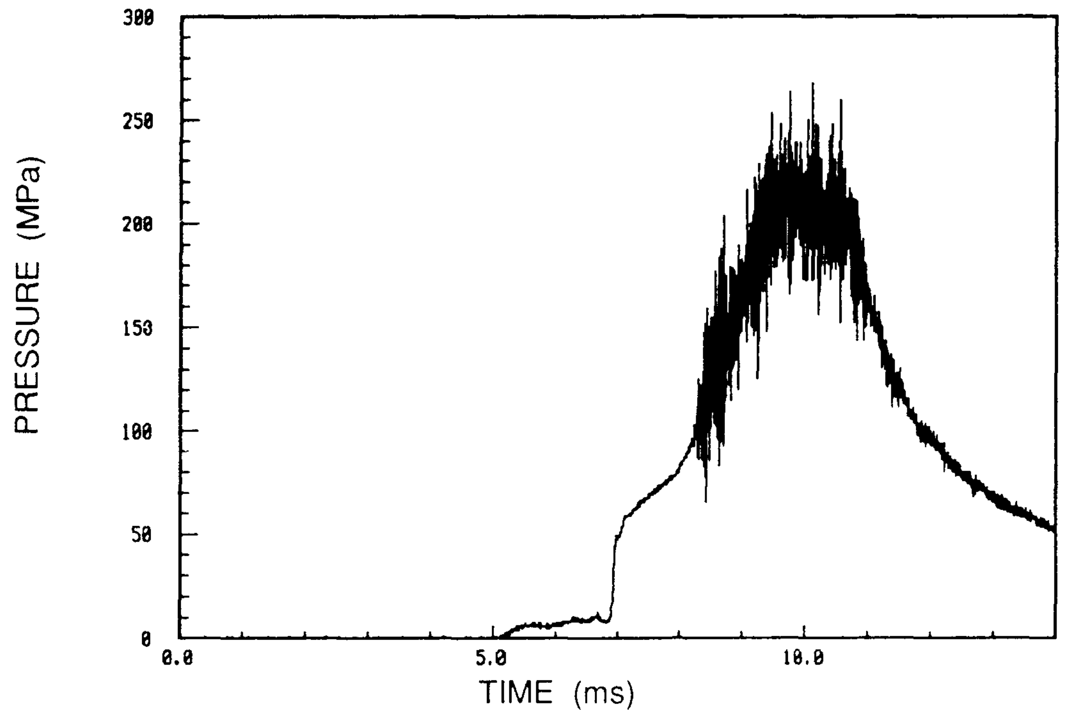

Figure 8. Test 415-68 Barrel 1 Pressure

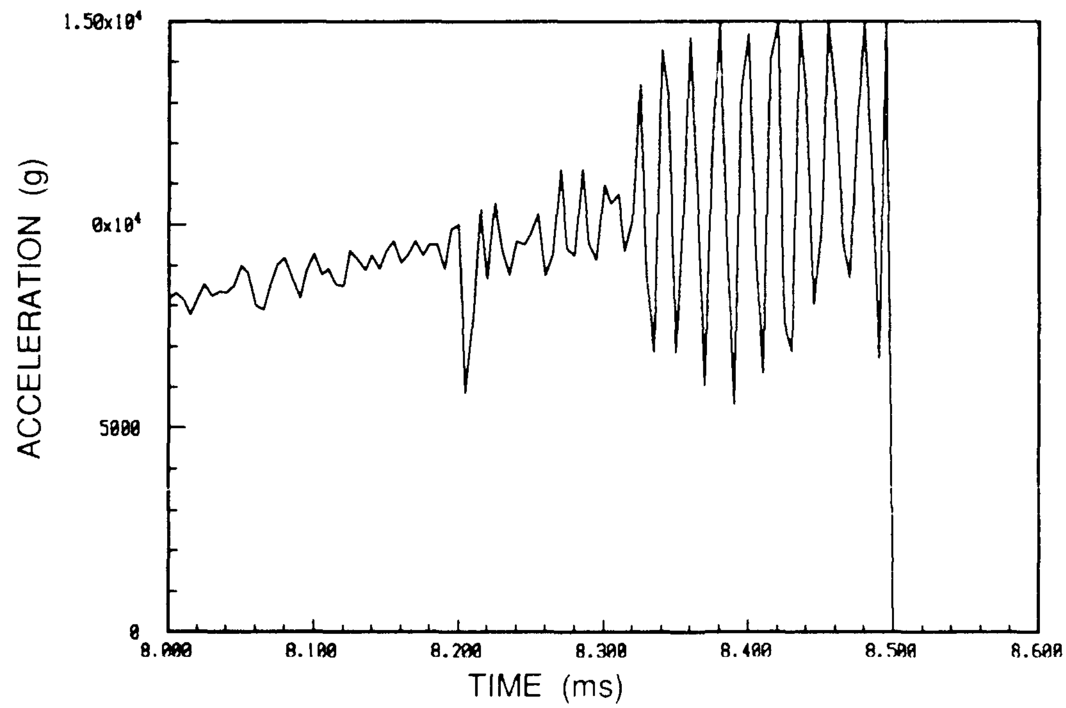

Figure 9. Test 415-68 Projectile Acceleration

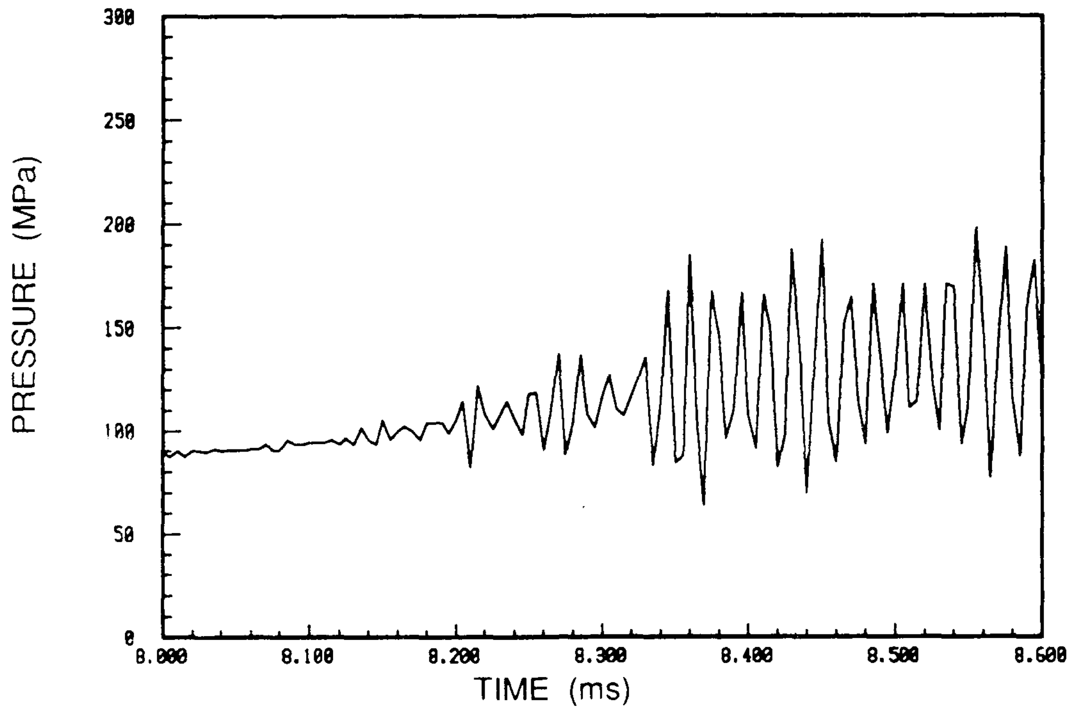

Figure 10. Test 415-68 Chamber Pressure (J120)

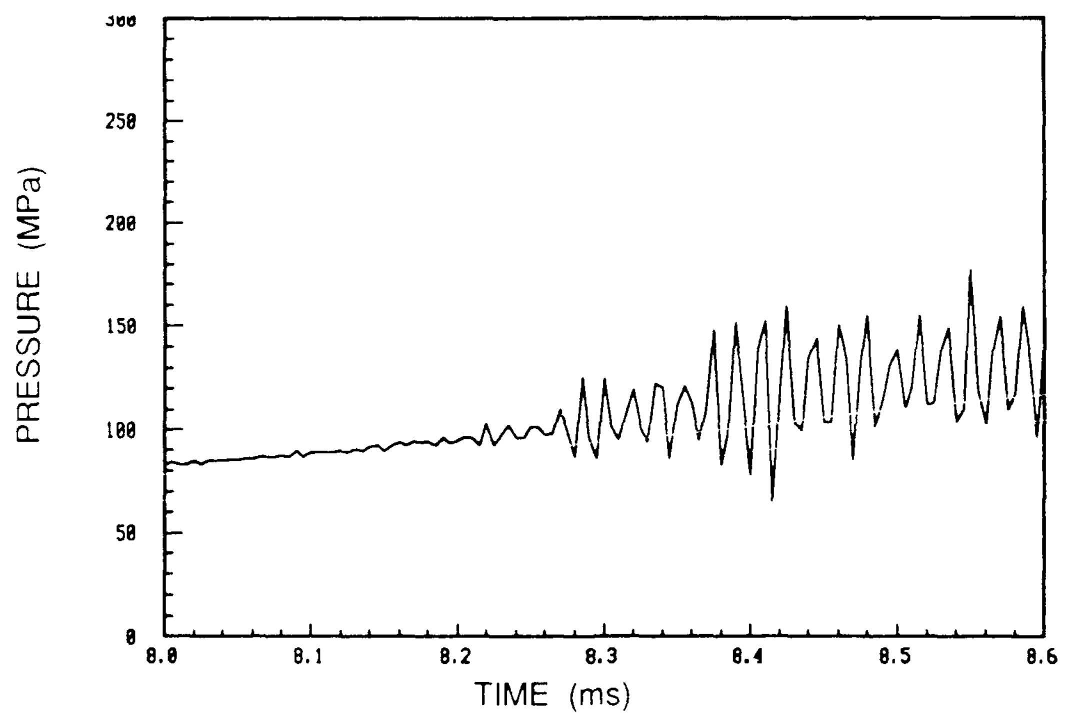

Figure 11. Test 415-68 Barrel 1 Pressure

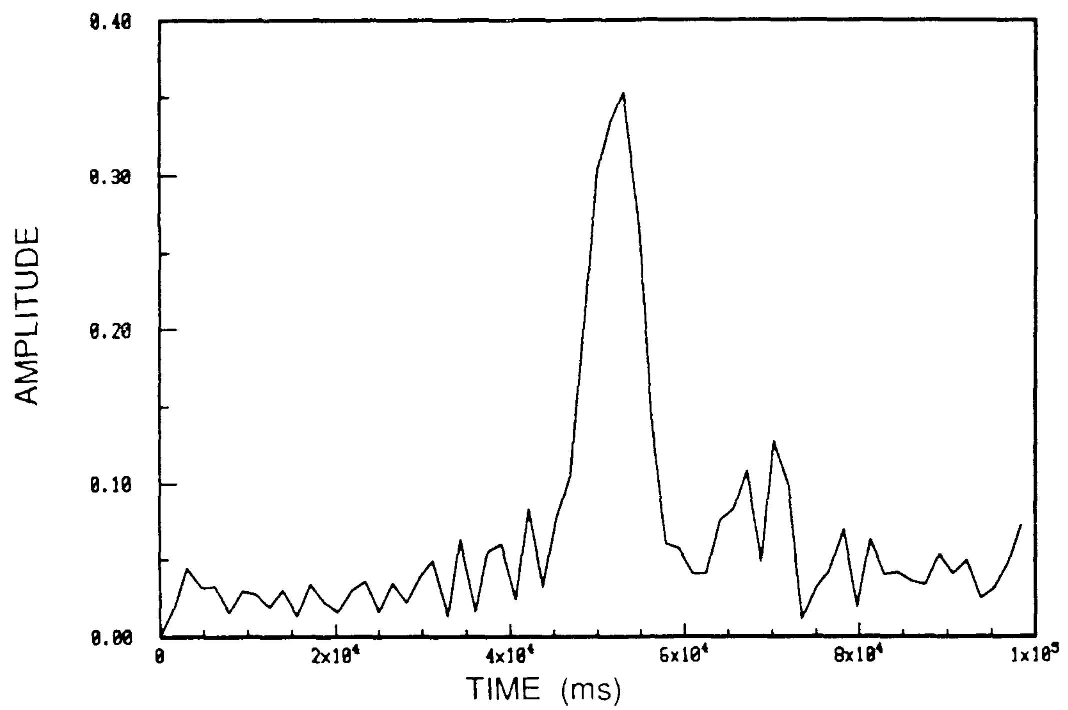

Figure 12. Test 415-68 FFT of Acceleration

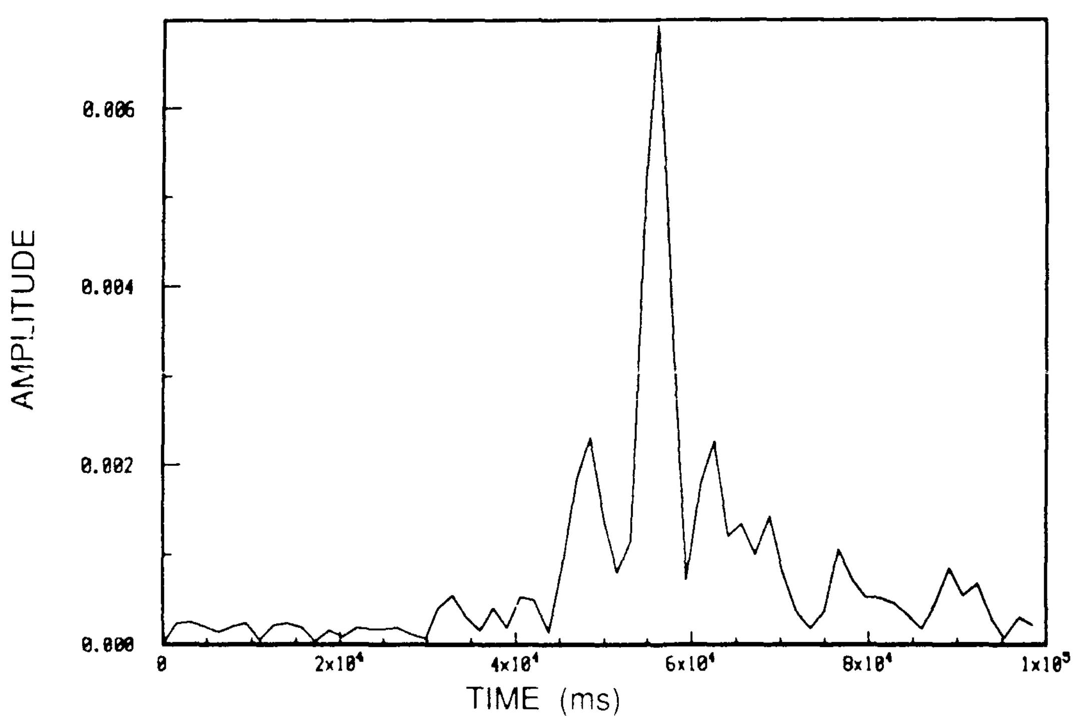

Figure 13. Test 415-68 FFT of Chamber Pressure

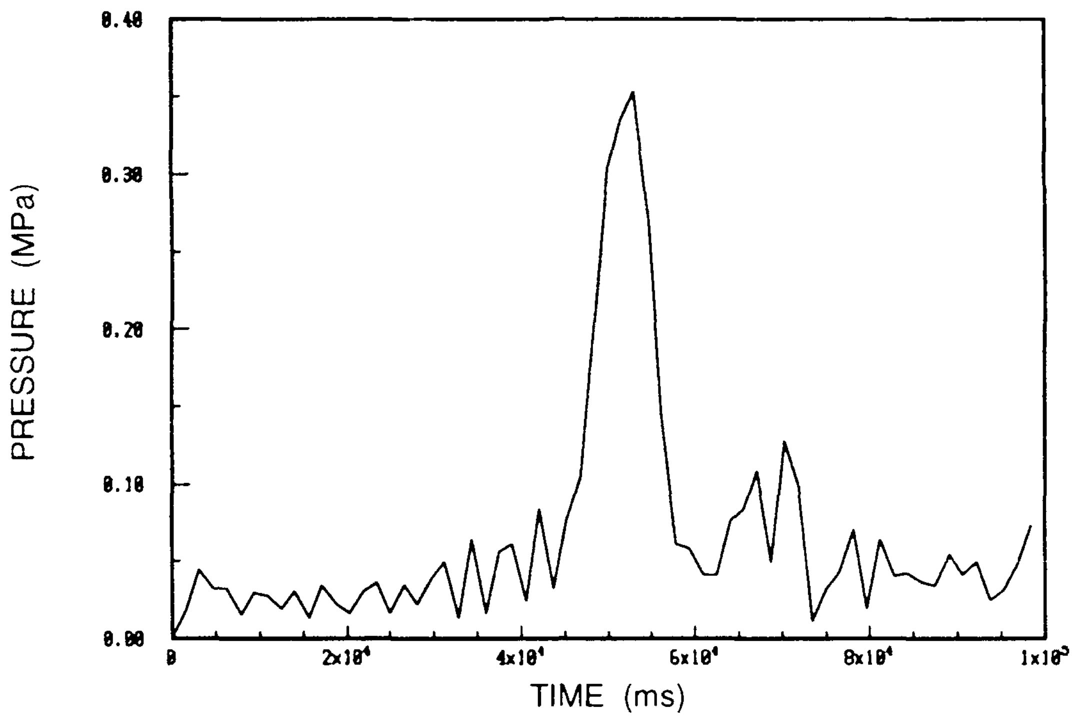

Figure 14. Test 415-68 FFT of Barrel 1 Pressure

Based on the limited test data that have been acquired, it is apparent that there are several areas of improvement that must be addressed. It is possible that as the projectile accelerated down tube, the extension rod may not have accelerated with it. In this case, the extension rod would have collapsed, explaining why limited data transmission distance was achieved. In addition, the transmission wires may have broken prematurely because of the fact that they were forced to "turn around" inside the tube as the extension rod accelerated.

4. CONCLUSIONS. Projectile base pressure and acceleration data are critical to the assessment of pressure oscillation effects in liquid propellant guns. The hardwire telemetry method demonstrated limited success. Use of this method provided acceleration data 4 cm beyond the transmission distance achieved without an extension rod. Projectile acceleration data were recorded that exhibited oscillatory behavior similar to that seen in both the chamber and in the barrel of the 30-mm Concept VI RLPG data. Further, it was determined that the dominant frequencies of the projectile accelerometer, chamber pressure in the J-plane, and the first barrel pressure were 53 kHz, 56 kHz, and 57 kHz, respectively, for test 415-68. Insufficient data has been collected to make further statements concerning the nature of the oscillations seen in the projectile acceleration data.

Several areas of improvement have been identified that must be addressed in the future. Investigation into a stronger or more rigid extension rod would be desirable. The projection of the extension rod out of the muzzle could possibly alleviate premature data transmission loss due to the "turning around" of the transmission wire in the bore. More

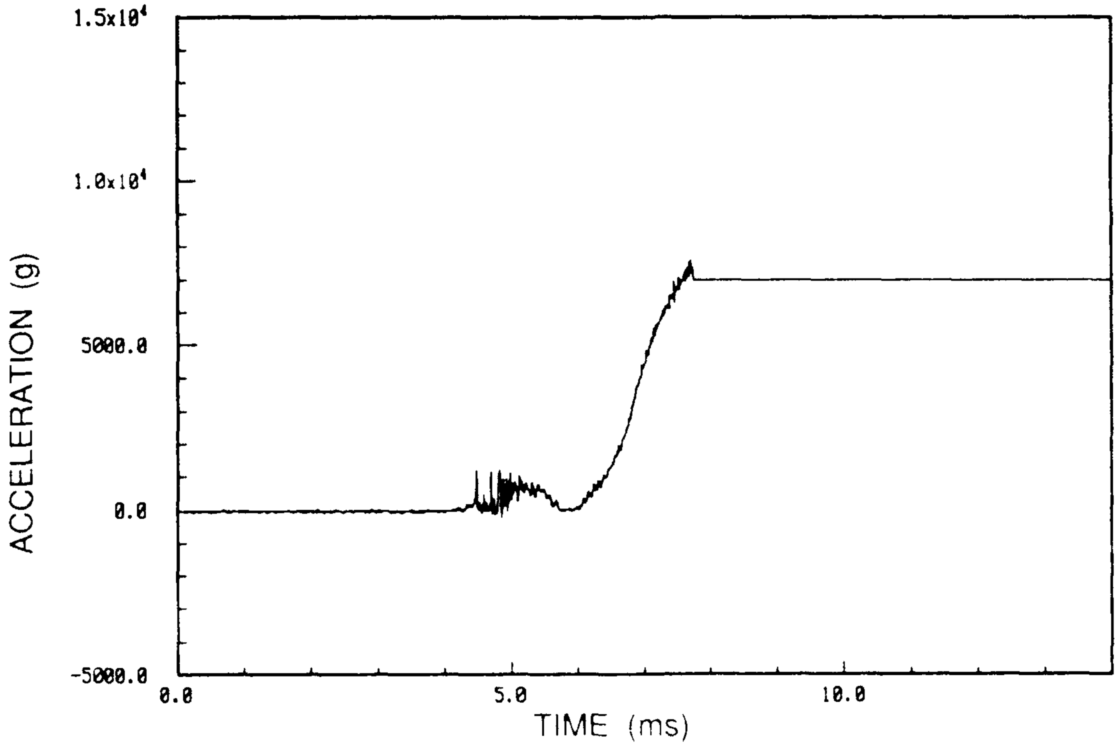

Figure 15. Test 415-74 Projectile Acceleration

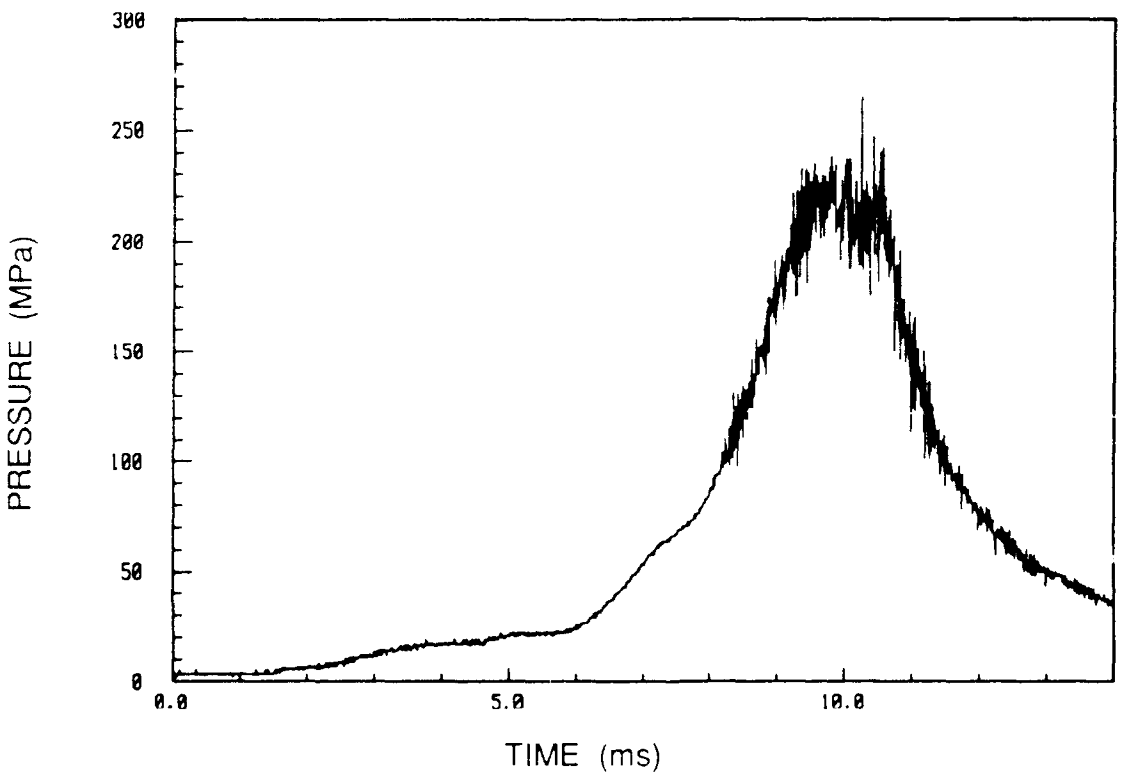

Figure 16. Test 415-74 Chamber Pressure (J120)

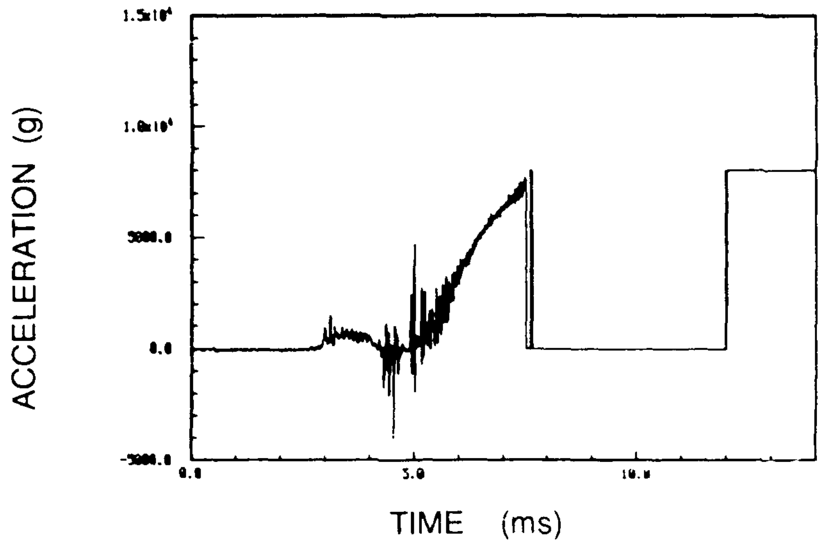

Figure 17. Test 415-75 Projectile Acceleration

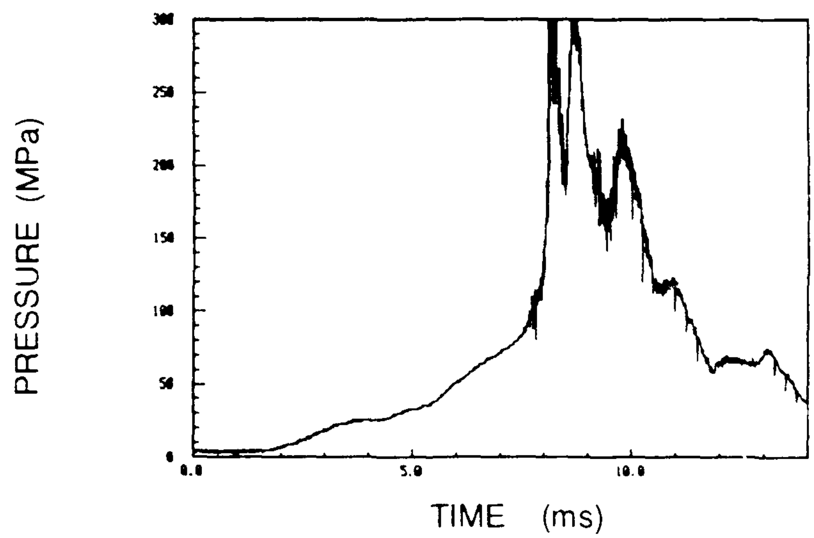

Figure 18. Test 415-75 Chamber Pressure (J120)

extensive diagnostics, such as flash X-rays and high speed photography could also be useful in studying the integrity of the extension rod.

5. ACKNOWLEDGMENTS. The authors would like to thank Mr. James DeSpirito, Mr. John Knapton, Mr. Carl Ruth, Mr. Cris Watson, Mr. Robert Kaste, and Dr. Thomas Minor of the Interior Ballistic Division, Ballistic Research Laboratory for their technical assistance with data analysis and program support. The authors would also like to thank Ms. Karen E. Marcou for her assistance in publishing this report.

6. REFERENCES.

Craig, W.D. "The Development of a "Hard-wire" Technique for Obtaining In-bore Data." Naval Weapons Laboratory Technical Report NWL-TR-3060, November 1973.

Evans, J.W. "Measurement of Interior Ballistic Performance Using FM/FM Radio Telemetry Techniques." U.S. Army Ballistic Research Laboratory Technical Report BRL-TR-2699, December 1985.

Knapton, J.D., C.A. Watson, and N.E. Boyer. "Pressure Oscillations During the Interior Ballistic Firing of Regenerative Liquid Propellant Guns." U.S. Army Ballistic Research Laboratory Technical Report [in publication].

Magoon, I., J. Haberl, and E. Purtee. "Preliminary Report on Test Firings of a 155-mm Regenerative Liquid Propellant Gun." Proceedings of the 26th JANNAF Combustion Meeting, CPIA Publication 529, vol. III, pp. 243-251, October 1989.

Mandzy, J., P.G. Cushman, and I. Magoon. "Technical Notes on Scaling Investigation of Concept VI." U.S. Army Ballistic Research Laboratory Contractor Report BRL-CR-580, August 1987.

Mandzy, J., I. Magoon, W.F. Morrison, and J.D. Knapton. "Preliminary Report on Test Firings of a 105-mm Regenerative Fixture." Proceedings of the 20th JANNAF Combustion Meeting, CPIA Publication 383, vol. II, pp. 161- 172, October 1983.

Morrow, W.P. "A Hard-wire Technique For Extracting Data From A Projectile During In-bore Environments." Harry Diamond Laboratory Report HDL-TM-72-27, October 1972.

Pate, R. and I. Magoon. "Preliminary Results from Ballistic Investigations in 30-mm Regenerative Liquid Propellant Gun Firings." Proceedings of the 22nd JANNAF Combustion Meeting, CPIA Publication 432, vol. II, pp. 213-224, October 1985.

Watson, C.A. "Pressure Oscillations in Regenerative Liquid Propellant Guns," Proceedings of the 1989 JANNAF Propulsion Meeting, CPIA Publication 515, vol. IV, pp. 345-354, May 1989.

No. of Copies	Organization
2	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145
1	Commander U.S. Army Materiel Command ATTN: AMCDRA-ST 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander U.S. Army Laboratory Command ATTN: AMSLC-DL 2800 Powder Mill Road Adelphi, MD 20783-1145
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-IMI-I Picatinny Arsenal, NJ 07806-5000
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07806-5000
1	Director Benet Weapons Laboratory U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-CCB-TL Watervliet, NY 12189-4050
(Unclass. only)1	Commander U.S. Army Armament, Munitions and Chemical Command ATTN: AMSMC-IMF-L Rock Island, IL 61299-5000
1	Director U.S. Army Aviation Research and Technology Activity ATTN: SAVRT-R (Library) M/S 219-3 Ames Research Center Moffett Field, CA 94035-1000

No. of Copies	Organization
1	Commander U.S. Army Missile Command ATTN: AMSMI-RD-CS-R (DOC) Redstone Arsenal, AL 35898-5010
1	Commander U.S. Army Tank-Automotive Command ATTN: ASQNC-TAC-DIT (Technical Information Center) Warren, MI 48397-5000
1	Director U.S. Army TRADOC Analysis Command ATTN: ATRC-WSR White Sands Missile Range, NM 88002-5502
1	Commandant U.S. Army Field Artillery School ATTN: ATSF-CSI Ft. Sill, OK 73503-5000
(Class. only)1	Commandant U.S. Army Infantry School ATTN: ATSH-CD (Security Mgr.) Fort Benning, GA 31905-5660
(Unclass. only)1	Commandant U.S. Army Infantry School ATTN: ATSH-CD-CSO-OR Fort Benning, GA 31905-5660
1	Air Force Armament Laboratory ATTN: WL/MNOI Eglin AFB, FL 32542-5000
	Aberdeen Proving Ground
2	Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP, H. Cohen
1	Cdr, USATECOM ATTN: AMSTE-TC
3	Cdr, CRDEC, AMCCOM ATTN: SMCCR-RSP-A SMCCR-MU SMCCR-MSI
1	Dir, VLAMO ATTN: AMSLC-VL-D
10	Dir, BRL ATTN: SLCBR-DD-T

No. of Copies	Organization
1	Commander U.S. Army Concepts Analysis Agency ATTN: D. Hardison 8120 Woodmont Ave. Bethesda, MD 20014
1	C.I.A. 01R/DB/Standard Washington, DC 20505
1	Director U.S. Army Ballistic Missile Defense Systems Command Advanced Technology Center P. O. Box 1500 Huntsville, AL 35807-3801
1	Chairman DOD Explosives Safety Board Room 856-C Hoffman Bldg. 1 2461 Eisenhower Ave. Alexandria, VA 22331-0600
1	Commander U.S. Army Materiel Command ATTN: AMCDE-DW 5001 Eisenhower Ave. Alexandria, VA 22333-5001
1	Department of the Army Office of the Product Manager 155mm Howitzer, M109A6, Paladin ATTN: SFAE-AR-HIP-IP, Mr. R. De Kleine Picatinny Arsenal, NJ 07806-5000
2	Commander Production Base Modernization Agency U.S. Army Armament Research, Development, and Engineering Center ATTN: AMSMC-PBM, A. Siklosi AMSMC-PBM-E, L. Laibson Picatinny Arsenal, NJ 07806-5000

No. of Copies	Organization
3	PEO-Armaments Project Manager Tank Main Armament Systems ATTN: AMCPM-TMA, K. Russell AMCPM-TMA-105 AMCPM-TMA-120, C. Roller Picatinny Arsenal, NJ 07806-5000
15	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-AEE SMCAR-AEE-B, A. Beardell D. Downs S. Einstein S. Westley S. Bernstein J. Rutkowski B. Brodman P. Bostonian R. Cirincione A. Grabowsky P. Hui J. O'Reilly N. Ross SMCAR-AES, S. Kaplowitz, Bldg. 321 Picatinny Arsenal, NJ 07806-5000
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-CCD, D. Spring SMCAR-CCH-V, C. Mandala Picatinny Arsenal, NJ 07806-5000
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-HFM, E. Barrieres Picatinny Arsenal, NJ 07806-5000
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-FSA-T, M. Salsbury Picatinny Arsenal, NJ 07806-5000

No. of Copies	Organization
1	Commander, USACECOM R&D Technical Library ATTN: ASQNC-ELC-IS-L-R, Myer Center Fort Monmouth, NJ 07703-5301
1	Commander U.S. Army Harry Diamond Laboratories ATTN: SLCHD-TA-L 2800 Powder Mill Rd. Adelphi, MD 20783-1145
1	Commandant U.S. Army Aviation School ATTN: Aviation Agency Fort Rucker, AL 36360
2	Program Manager U.S. Army Tank-Automotive Command ATTN: AMCPM-ABMS, T. Dean (2 cps) Warren, MI 48092-2498
1	Program Manager U.S. Army Tank-Automotive Command Fighting Vehicles Systems ATTN: AMCPM-BFVS Warren, MI 48092-2498
1	President U.S. Army Armor & Engineer Board ATTN: ATZK-AD-S Fort Knox, KY 40121
1	Project Manager U.S. Army Tank-Automotive Command M-60 Tank Development ATTN: AMCPM-ABMS Warren, MI 48092-2498
1	Director HQ, TRAC RPD ATTN: ATCD-MA Fort Monroe, VA 23651-5143
2	Director U.S. Army Materials Technology Laboratory ATTN: SLCMT-ATL (2 cps) Watertown, MA 02172-0001

No. of Copies	Organization
1	Commander U.S. Army Research Office ATTN: Technical Library P.O. Box 12211 Research Triangle Park, NC 27709-2211
1	Commander U.S. Army Belvoir Research and Development Center ATTN: STRBE-WC Fort Belvoir, VA 22060-5006
1	Director U.S. Army TRAC-Ft. Lee ATTN: ATRC-L, Mr. Cameron Fort Lee, VA 23801-6140
1	Commandant U.S. Army Command and General Staff College Fort Leavenworth, KS 66027
1	Commandant U.S. Army Special Warfare School ATTN: Rev and Trng Lit Div Fort Bragg, NC 28307
3	Commander Radford Army Ammunition Plant ATTN: SMCAR-QA/HI LIB (3 cps) Radford, VA 24141-0298
1	Commander U.S. Army Foreign Science and Technology Center ATTN: AMXST-MC-3 220 Seventh Street, NE Charlottesville, VA 22901-5396
2	Commander Naval Sea Systems Command ATTN: SEA 62R SEA 64 Washington, DC 20362-5101
1	Commander Naval Air Systems Command ATTN: AIR-954-Technical Library Washington, DC 20360

No. of Copies	Organization
1	Assistant Secretary of the Navy (R, E, and S) ATTN: R. Reichenbach Room 5E787 Pentagon Bldg Washington, DC 20375
1	Naval Research Laboratory Technical Library Washington, DC 20375
2	Commandant U.S. Army Field Artillery Center and School ATTN: ATSF-CO-MW, E. Dublisky (2 cps) Fort Sill, OK 73503-5600
1	Office of Naval Research ATTN: Code 473, R. S. Miller 800 N. Quincy Street Arlington, VA 22217-9999
3	Commandant U.S. Army Armor School ATTN: ATZK-CD-MS, M. Falkovitch (3 cps) Armor Agency Fort Knox, KY 40121-5215
2	Commander U.S. Naval Surface Warfare Center ATTN: J. P. Consaga C. Gotzmer Indian Head, MD 20640-5000
4	Commander Naval Surface Warfare Center ATTN: Code 240, S. Jacobs Code 730 Code R-13, K. Kim R. Bernecker Silver Spring, MD 20903-5000
2	Commanding Officer Naval Underwater Systems Center ATTN: Code 5B331, R. S. Lazar Technical Library Newport, RI 02840

No. of Copies	Organization
5	Commander Naval Surface Warfare Center ATTN: Code G33, J. L. East W. Burrell J. Johndrow Code G23, D. McClure Code DX-21 Technical Library Dahlgren, VA 22448-5000
3	Commander Naval Weapons Center ATTN: Code 388, C. F. Price Code 3895, T. Parr Information Science Division China Lake, CA 93555-6001
1	OSD/SDIO/IST ATTN: Dr. Len Caveny Pentagon Washington, DC 20301-7100
3	Commander Naval Ordnance Station ATTN: T. C. Smith D. Brooks Technical Library Indian Head, MD 20640-5000
1	AL/TSTL (Technical Library) ATTN: J. Lamb Edwards AFB, CA 93523-5000
1	AFATL/DLYV Eglin AFB, FL 32542-5000
1	AFATL/DLXP Eglin AFB, FL 32542-5000
1	AFATL/DLJE Eglin AFB, FL 32542-5000
1	NASA/Lyndon B. Johnson Space Center ATTN: NHS-22 Library Section Houston, TX 77054

No. of Copies	Organization
1	AFELM, The Rand Corporation ATTN: Library D 1700 Main Street Santa Monica, CA 90401-3297
3	AAI Corporation ATTN: J. Hebert J. Frankle D. Cleveland P.O. Box 126 Hunt Valley, MD 21030-0126
2	Aerojet Solid Propulsion Company ATTN: P. Micheli L. Torreyson Sacramento, CA 96813
1	Atlantic Research Corporation ATTN: M. King 5390 Cherokee Ave. Alexandria, VA 22312-230.
3	AL/LSCF ATTN: J. Levine L. Quinn T. Edwards Edwards AFB, CA 93523-5000
1	AVCO Everett Research Laboratory ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149-5936
2	Calspan Corporation ATTN: C. Murphy (2 cps) P.O. Box 400 Buffalo, NY 14225-0400
2	General Electric Company Tactical Systems Department ATTN: J. Mandzy J. Haberl 100 Plastics Ave. Pittsfield, MA 01201-3698
1	IITRI ATTN: M. J. Klein 10 W. 35th Street Chicago, IL 60616-3799

No. of Copies	Organization
1	Hercules, Inc. Allegheny Ballistics Laboratory ATTN: William B. Walkup P.O. Box 210 Rocket Center, WV 26726
1	Hercules, Inc. Radford Army Ammunition Plant ATTN: E. Hibshman Radford, VA 24141-0299
3	Director Lawrence Livermore National Laboratory ATTN: L-355, A. Buckingham M. Finger L-324, M. Constantino P.O. Box 808 Livermore, CA 94550-0622
1	Olin Corporation Badger Army Ammunition Plant ATTN: F. E. Wolf Baraboo, WI 53913
2	Olin Ordnance ATTN: E. J. Kirschke A. F. Gonzalez P.O. Box 222 St. Marks, FL 32355-0222
1	Paul Gough Associates, Inc. ATTN: Dr. Paul S. Gough 1048 South Street Portsmouth, NH 03801-5423
1	Physics International Company ATTN: Library, H. Wayne Wampler 2700 Merced Street San Leandro, CA 98457-5602
1	Princeton Combustion Research Laboratory, Inc. ATTN: M. Summerfield 475 U.S. Highway One Monmouth Junction, NJ 08852-9650

No. of Copies	Organization
2	Rockwell International Rocketdyne Division ATTN: BA08, J.E. Flanagan J. Gray 6633 Canoga Ave. Canoga Park, CA 91303-2703
1	Thiokol Corporation Huntsville Division ATTN: Technical Library Huntsville, AL 35807
1	Sverdrup Technology, Inc. ATTN: Dr. John Deur 2001 Aerospace Parkway Brook Park, OH 44142
2	Thiokol Corporation Elkton Division ATTN: R. Biddle Technical Library P.O. Box 241 Elkton, MD 21921-0241
1	Veritay Technology, Inc. ATTN: E. Fisher 4845 Millersport Highway East Amherst, NY 14501-0305
1	Universal Propulsion Company ATTN: H. J. McSpadden Black Canyon Stage 1 Box 1140 Phoenix, AZ 84029
1	Battelle ATTN: TACTEC Library, J.N. Huggins 505 King Ave. Columbus, OH 43201-2693
1	Brigham Young University Department of Chemical Engineering ATTN: M. Beckstead Provo, UT 84601

No. of Copies	Organization
1	California Institute of Technology 204 Karman Laboratory Main Stop 301-46 ATTN: F.E.C. Culick 1201 E. California Street Pasadena, CA 91109
1	California Institute of Technology Jet Propulsion Laboratory ATTN: L. D. Strand, MS 512/102 4800 Oak Grove Drive Pasadena, CA 91109-8099
1	University of Illinois Department of Mechanical/Industrial Engineering ATTN: H. Krier 144 MEB; 1206 N. Green Street Urbana, IL 61801-2978
1	University of Massachusetts Department of Mechanical Engineering ATTN: K. Jakus Amherst, MA 01002-0014
1	University of Minnesota Department of Mechanical Engineering ATTN: E. Fletcher Minneapolis, MN 55414-3368
3	Georgia Institute of Technology School of Aerospace Engineering ATTN: B.T. Zinn E. Price W.C. Strahle Atlanta, GA 30332
1	Institute of Gas Technology ATTN: D. Gidaspow 3424 S. State Street Chicago, IL 60616-3896
1	Johns Hopkins University Applied Physics Laboratory Chemical Propulsion Information Agency ATTN: T. Christian Johns Hopkins Road Laurel, MD 20707-0690

No. of Copies	Organization
1	Massachusetts Institute of Technology Department of Mechanical Engineering ATTN: T. Toong 77 Massachusetts Ave. Cambridge, MA 02139-4307
1	Pennsylvania State University Applied Research Laboratory ATTN: G. M. Faeth University Park, PA 16802-7501
1	Pennsylvania State University Department of Mechanical Engineering ATTN: K. Kuo University Park, PA 16802-7501
1	Purdue University School of Mechanical Engineering ATTN: J. R. Osborn TSPC Chaffee Hall West Lafayette, IN 47907-1199
1	SRI International Propulsion Sciences Division ATTN: Technical Library 333 Ravenwood Ave. Menlo Park, CA 94025-3493
1	Rensselaer Ploytechnic Institute Department of Mathematics Troy, NY 12181
2	Director Los Alamos Scientific Laboratory ATTN: T3, D. Butler M. Division, B. Craig P.O. Box 1663 Los Alamos, NM 87544
2	Director Sandia National Laboratories ATTN: R. Carling R. Rychnovaky P.O. Box 5800 Albuquerque, NM 87185

No. of Copies	Organization
1	General Applied Sciences Laboratory ATTN: J. Erdos 77 Raynor Ave. Ronkonkama, NY 11779-6649
1	Battelle PNL ATTN: Mr. Mark Garnich P.O. Box 999 Richland, WA 99352
1	Stevens Institute of Technology Davidson Laboratory ATTN: R. McAlevy, III Castle Point Station Hoboken, NJ 07030-5907
1	Rutgers University Department of Mechanical and Aerospace Engineering ATTN: S. Temkin University Heights Campus New Brunswick, NJ 08903
1	University of Southern California Mechanical Engineering Department ATTN: 0HE200, M. Gerstein Los Angeles, CA 90089-5199
2	University of Utah Department of Chemical Engineering ATTN: A. Baer G. Flandro Salt Lake City, UT 84112-1194
1	Washington State University Department of Mechanical Engineering ATTN: C. T. Crowe Pullman, WA 99163-5201
1	Alliant Techsystems, Inc. ATTN: R. E. Tompkins MN38-3300 5700 Smetana Drive Minnetonka, MN 55343
1	Science Applications, Inc. ATTN: R. B. Edelman 23146 Cumorah Crest Drive Woodland Hills, CA 91364-3710

No. of Copies	Organization
1	Battelle Columbus Laboratories ATTN: Mr. Victor Levin 505 King Ave. Columbus, OH 43201-2693
1	Allegheny Ballistics Laboratory Propulsion Technology Department Hercules Aerospace Company ATTN: Mr. Thomas F. Farabaugh P.O. Box 210 Rocket Center, WV 26726
1	MBR Research Inc. ATTN: Dr. Moshe Ben-Reuven 601 Ewing St., Suite C-22 Princeton, NJ 08540
	Aberdeen Proving Ground
1	Cdr, CSTA ATTN: STECS-PO, R. Hendricksen

USER EVALUATION SHEET/CHANGE OF ADDRESS

This laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers below will aid us in our efforts.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ______

2. How, specifically, is the report being used? (Information source, design data, procedure, source of ideas, etc.) ______

3. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ______

4. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ______

BRL Report Number BRL-TR-3285 Division Symbol ______

Check here if desire to be removed from distribution list. ____

Check here for address change. ____

Current address: Organization ______
Address ______

DEPARTMENT OF THE ARMY
Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

OFFICIAL BUSINESS

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT No 0001, APG, MD

Postage will be paid by addressee

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066